Correlation of Doppler Noise During Solar Conjunctions With Fluctuations in Solar Activity

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In a previous report, a geometric model to predict doppler noise during solar conjunctions was developed. In this report, deviations between observed doppler noise and the noise model are analyzed. Based on the analysis, it is tentatively concluded that deviations between the observed noise and the model are due to short-term fluctuations in solar activity as seen along the signal path, and not to solar/antenna structure effects or system noise temperature.

I. Introduction

In the preceding report (Ref. 1), the authors, after considering doppler noise estimates accumulated during the 1975 solar conjunctions of Pioneer 10, Pioneer 11, and Helios 1, developed a geometric solar noise model for 2-way, 60-second-sample-rate doppler data as follows:

$$NOISE_P\,(\mathrm{Hz}) = \begin{cases} 0.003, & ISI \leq 223 \\ K_1\,(ISI)^{1+K_2}, & ISI > 223 \end{cases}$$

where

$$K_1 = 2.8 \times 10^{-6}$$

$$K_2 = 2.9 \times 10^{-1}$$

$$ISI = \frac{\beta}{\sin \alpha}$$

α = Sun–Earth–probe angle, degrees

β = Earth–Sun–probe angle, degrees

In this report, residuals between the observed doppler noise and the predicted doppler noise, in percent deviation from predicted,[1] are formed as follows:

$$\text{Residual} = \frac{\text{observed noise} - \text{predicted noise}}{\text{predicted noise}} \times 100$$

where

$$\text{Residual} = \text{residual in percent}$$

$$\text{Observed noise} = \text{observed noise (DOY)}$$

$$\text{Predicted noise} = NOISE_P\,(\alpha(\text{DOY}), \beta\,(\text{DOY}))$$

$$\text{DOY} = \text{day of year}$$

These residuals are herein analyzed, and, from this analysis, the authors draw the tentative conclusion that

[1]The residuals are put in this form because the data span almost three orders of magnitude.

the deviations in the observed data from the $NOISE_P$ model are for the most part due to short-term fluctuations in solar activity as seen along the signal path.

II. Doppler Noise due to Solar/Antenna Structure Effects and System Noise Temperature

During previous solar conjunctions, it was observed that there existed periods when the doppler noise rose dramatically and then receded back to follow a course of more orderly progression with the Sun–Earth–probe (SEP) angle. It was conjectured at the time that these "spikes" were due to solar/antenna structure effects. Additionally, it was hypothesized by some observers that part of the increase in observed doppler noise could be accounted for by the increase in system noise temperature. If either of the above were significant, one might expect to see a systematic deviation of the doppler noise residuals when plotted collectively as a function of SEP (since both effects would only be functions of SEP while the noise model is a function of both Earth–Sun–probe (ESP) angle and SEP). Such a graph is seen as Fig. 1, and one would certainly be hard pressed to detect any significant systematic trends in the figure. It thus seems reasonable to assume that neither solar/antenna structure effects nor system noise temperature are significant factors in the high doppler noise during solar conjunctions.

III. Multimission Correlation of Doppler Noise Residuals

Two of the assumptions made in the original derivation of the $NOISE_P$ solar noise model were:

(1) Constant solar radiation and emission of charged particles.

(2) Solar radial symmetry (as opposed to radial asymmetry and rotation!).

These assumptions were useful in deriving an "average" geometric model; however, both assumptions ignore a time-dependent component of solar radiation and charged-particle density. Therefore, one might expect to gain some insight by examining the residuals as a function of time (i.e., DOY). If the residuals display well-defined trends as a function of time, one might think that time-dependent fluctuations in solar activity along the signal path were the cause; in particular, the argument would be additionally strengthened if the same trends were seen in more than one mission (and hence at different SEPs for the same DOY). Figure 2 presents Pioneer 10, Pioneer 11, and Helios 1 residuals as a function of time (DOY 82 to DOY 132); in this figure a very strong similarity is seen in the Pioneer 10 and 11 signatures, while a much weaker similarity is seen between the Pioneer 11 and Helios 1 signatures. Figure 3 presents Pioneer 10 and 11 residuals for an earlier period (DOY 64 and 84), and, once again, a similarity in residual signatures is observed for both spacecraft. Noting the strong evidence of multimission correlation of doppler noise with time as presented in Figs. 2 and 3, it seems reasonable to look to fluctuations in solar activity as the predominant cause of deviations in observed doppler noise from the $NOISE_P$ model.

IV. Correlation of Doppler Noise Residuals With Fluctuations in Solar Activity

The major fluctuation in solar activity as seen at Earth is an approximate 4-week cycle, which is due to solar radial asymmetry and a solar rotation rate of slightly less than 4 weeks. A secondary effect within this cycle is the intrinsic variation of solar activity with time of any given area on the solar surface. All common indices of solar activity, such as number of sunspots, solar flare index, solar energy flux, move (roughly) in unison with the basic cycle. To observe if any correlation exists between doppler noise residuals and the solar rotation cycle, the daily solar energy flux (Ottawa, 2800 MHz; see Ref. 2) was chosen for convenience as a representative index. Figure 4 presents the Pioneer 10, Pioneer 11, and Helios 1 noise residuals as compared to observed solar energy flux, with both as functions of DOY. The residuals and the solar flux obviously seem to bear some similarity to each other in terms of a basic several-week cycle, although in some regions the residuals seem to be in phase with the flux and, in other regions, out of phase. A possible explanation for a "variable lag" between Earth-observed solar activity and observed doppler noise residuals is the rapidly changing orientation of the signal path to the (rotating) Sun. A situation which would alleviate the complexity of a changing signal path with respect to the (rotating) Sun would be a spacecraft with a near static Earth–Sun–spacecraft geometry over some period of time. For this situation, one might expect the "phase difference" between doppler noise residuals and Earth-observed solar activity to be nearly a constant. Helios 1 exhibited just this type of geometry after the first superior solar conjunction; during an appropriate two-month period, the ESP and SEP varied only slightly. Figure 5 presents the Helios 1 doppler noise residuals during this period[2] as compared to observed solar flux which has been advanced to a later date by 10 days, and the correlation seems uncanny. Although the above embodies a great deal of guesswork, it seems reasonable to assume the following:

(1) The $NOISE_P$ model is a good geometric representation for "average" solar activity.

(2) Deviations from the $NOISE_P$ model are primarily due to fluctuations in solar activity as seen along the signal path; these fluctuations are a result of:

(a) Radial asymmetry of solar activity combined with solar rotation.

(b) Variation with time of solar activity for any region of the solar surface.

As a final consideration, the Sun is currently near the bottom of a long-term (several year) cycle and presumably the $NOISE_P$ (or any other) model would have to be updated from time to time to reflect long-term changes in "average" solar activity.

[2]The data after DOY 203 were not part of the original data base, but were abstracted from the monthly tracking reports.

V. Summary

In a previous report, the authors developed a geometric model for solar-induced doppler noise. This report analyzes the signatures left in the observed doppler noise after subtracting the noise model. From this analysis, the following observations are made:

(1) Multimission noise residuals do not appear to correlate with the SEP angle.

(2) Multimission noise residuals do correlate as a function of DOY.

(3) Multimission noise residuals appear to correlate in some fashion with short-term fluctuations in solar activity.

from which the following tentative inferences are drawn:

(1) Deviations from the $NOISE_P$ model are not related to solar/antenna structure effects or system noise temperature.

(2) Deviations from the $NOISE_P$ model are predominantly related to short-term fluctuations in solar activity as seen along the signal path, these fluctuations in turn resulting from:

(a) Radial asymmetry of solar activity, combined with solar rotation.

(b) Variation with time of solar activity for any region of the solar surface.

References

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2. *Solar-Geophysical Data*, Prompt Reports 367-1, 368-1, 369-1, 370-1, and 373-1, National Oceanic and Atmospheric Administration, Department of Commerce, Ashville, N. C., 1975.

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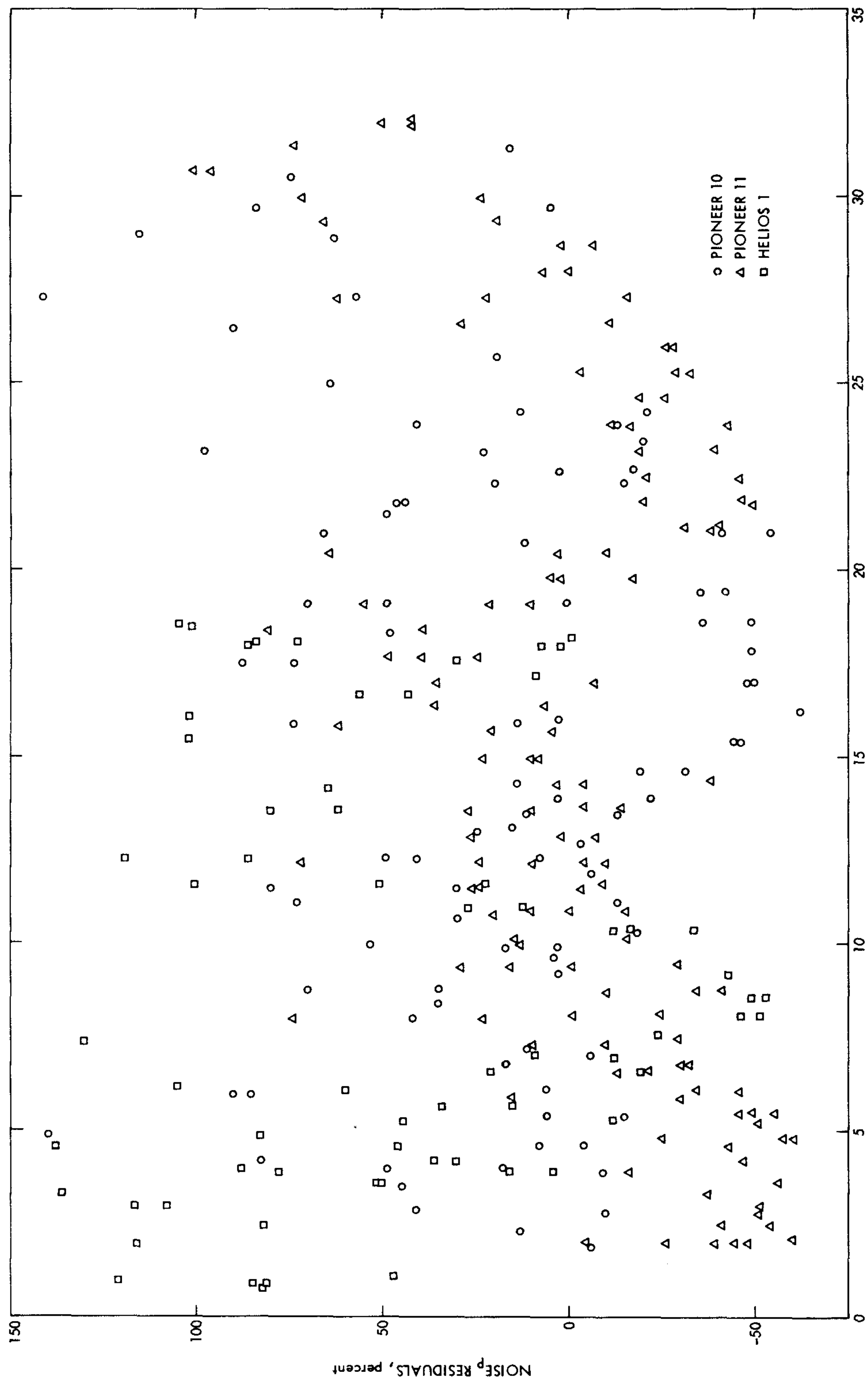

Fig. 1. Multimission *NOISE*$_p$ residuals vs Sun–Earth–probe angle

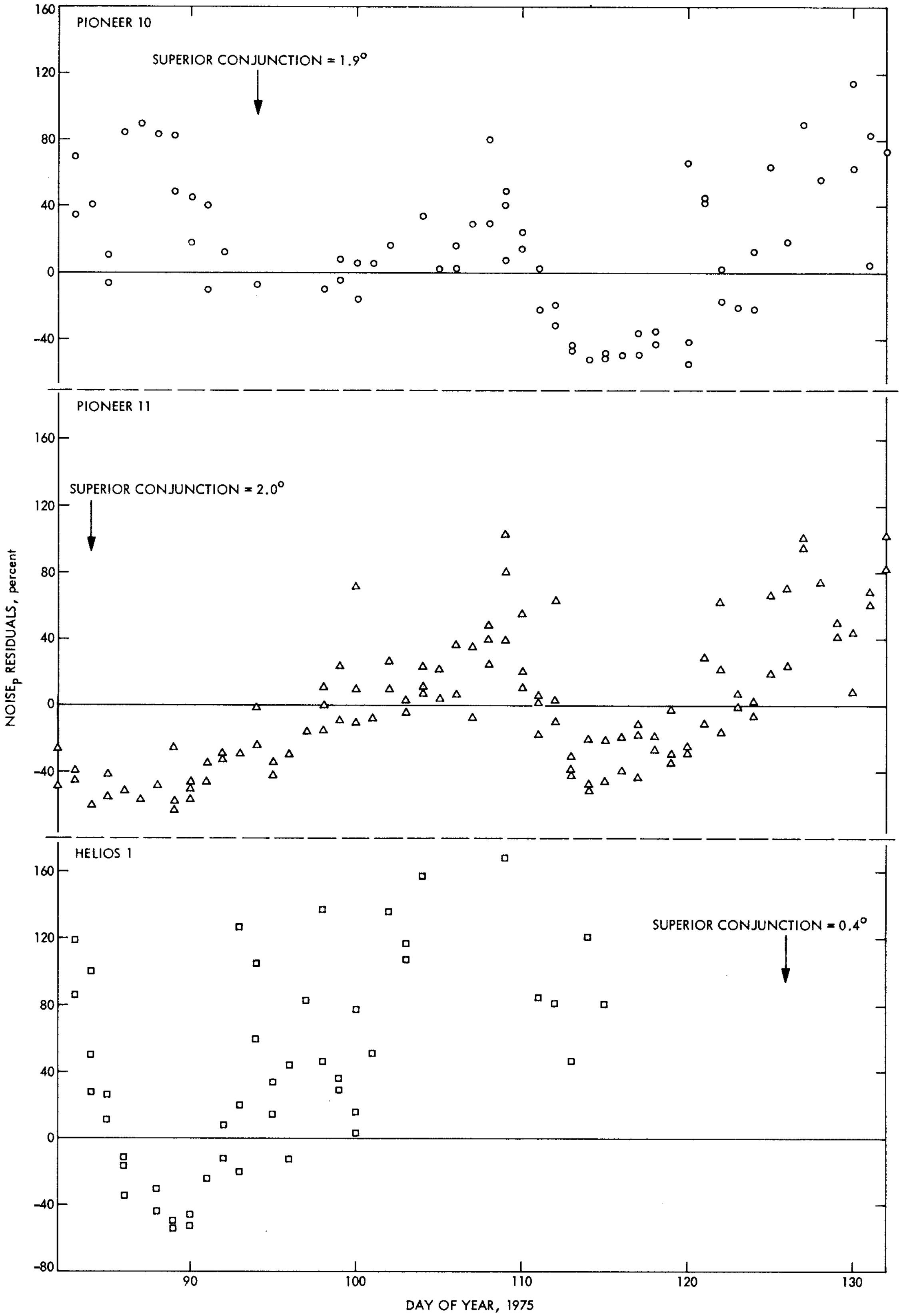

Fig. 2. Separate mission $NOISE_p$ residuals vs day of year

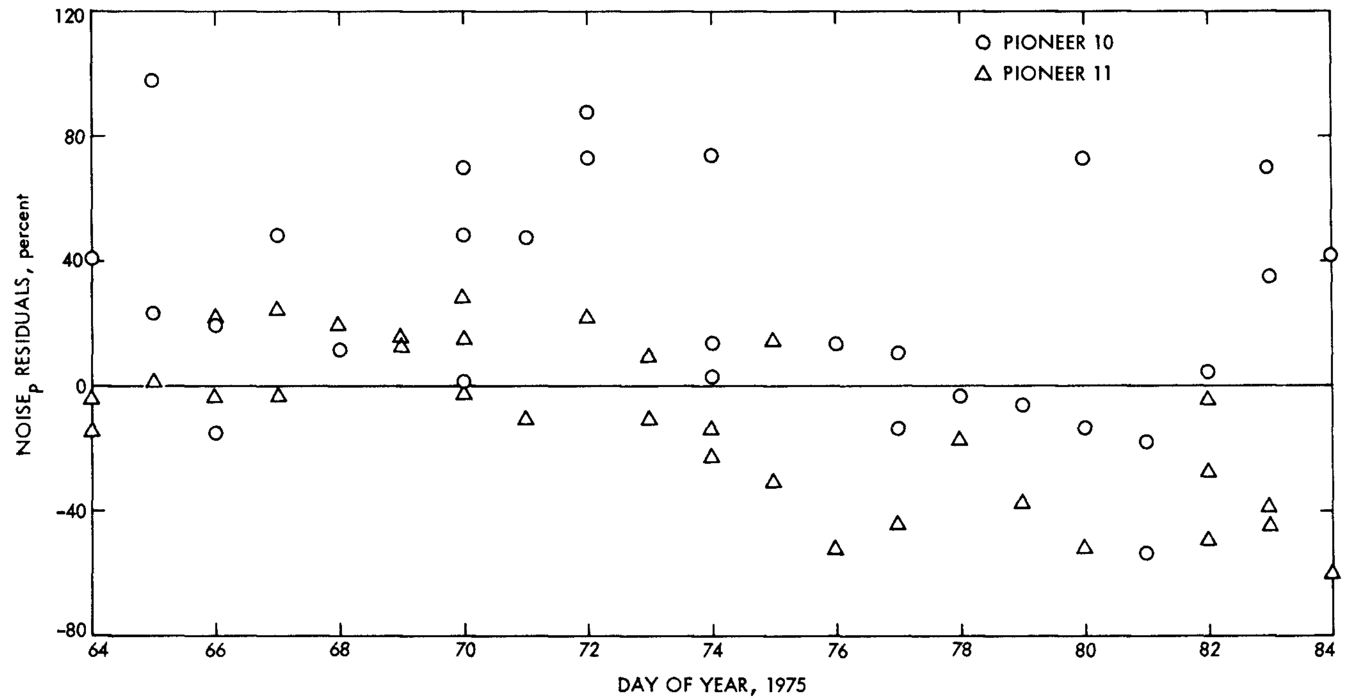

Fig. 3. Pioneer 10 and 11 $NOISE_p$ residuals vs day of year

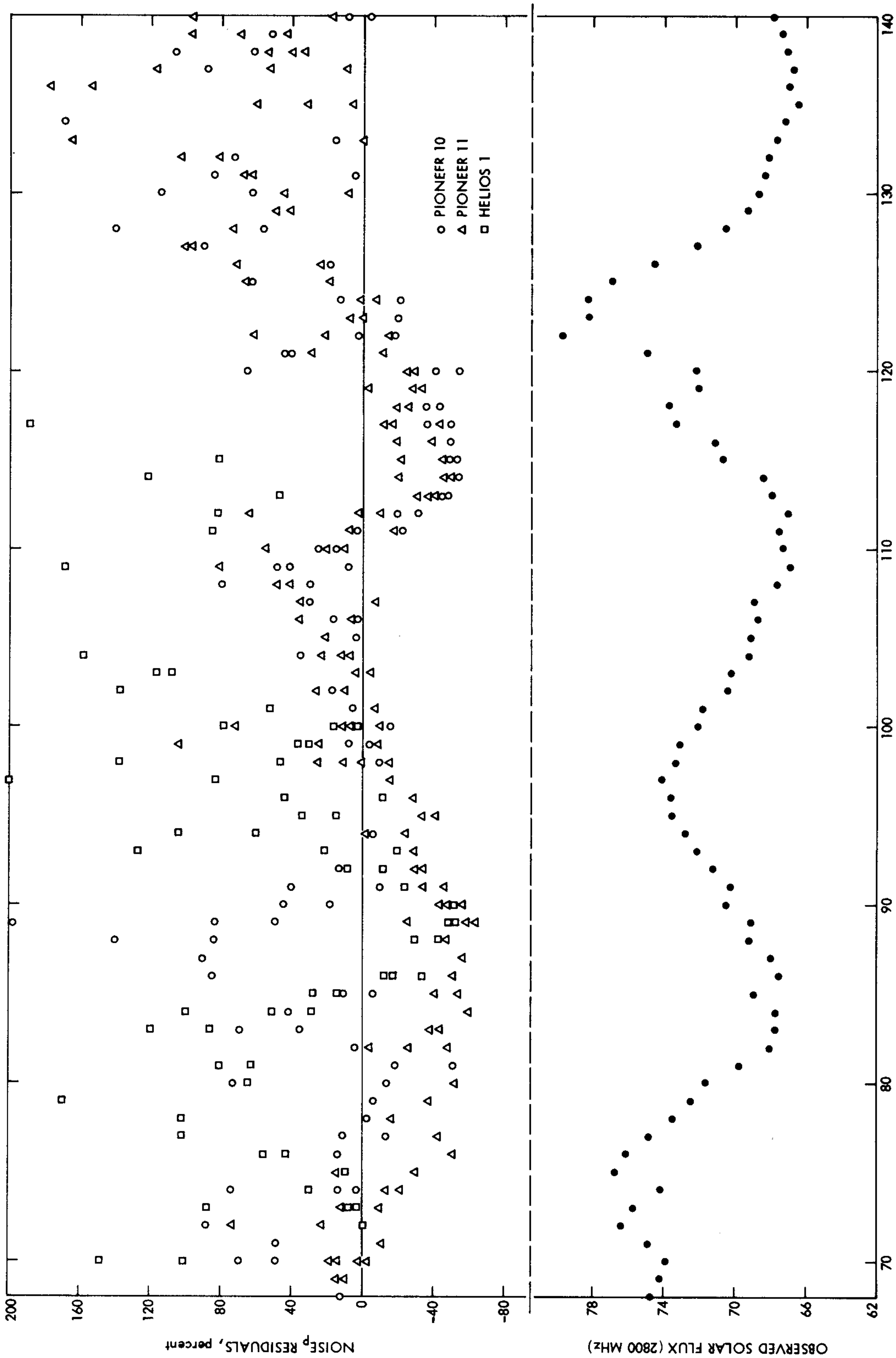

Fig. 4. Multimission $NOISE_p$ residuals/observed solar flux vs day of year

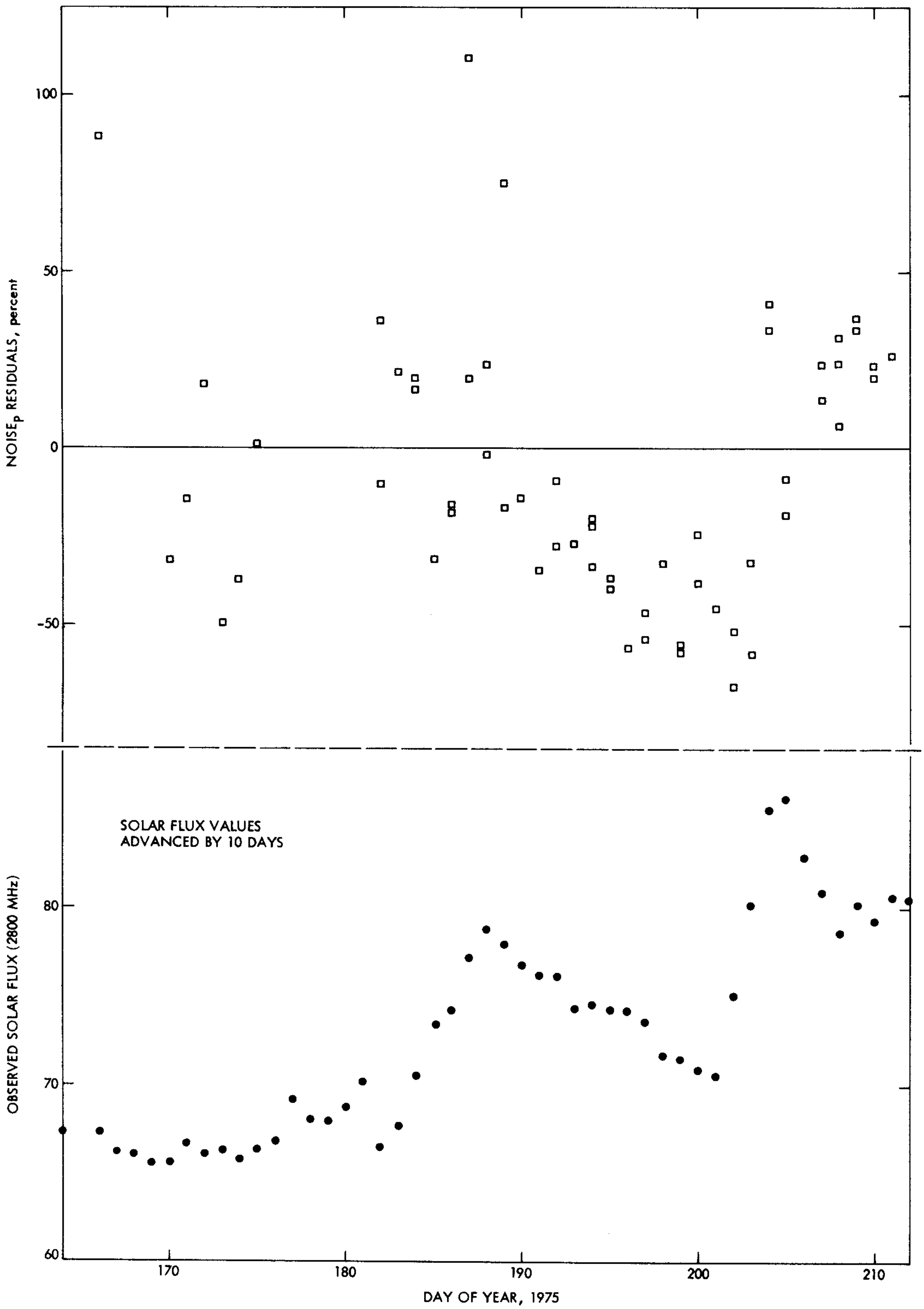

Fig. 5. Helios 1 *NOISE$_p$* residuals/solar flux vs day of year